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Brady

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(54) **METHOD AND APPARATUS FOR COOLING THE AMBIENT AIR AT THE INLET OF GAS COMBUSTION TURBINE GENERATORS**

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F02C 7/141	(2006.01)
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CPC ***F02C 7/141*** (2013.01); ***F02C 7/057*** (2013.01); ***F02C 7/143*** (2013.01); ***F02C 7/1435*** (2013.01)

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CPC F02C 7/04; F02C 7/143; F02C 7/1435; F02C 7/16; F01D 25/12; F01D 2260/212;
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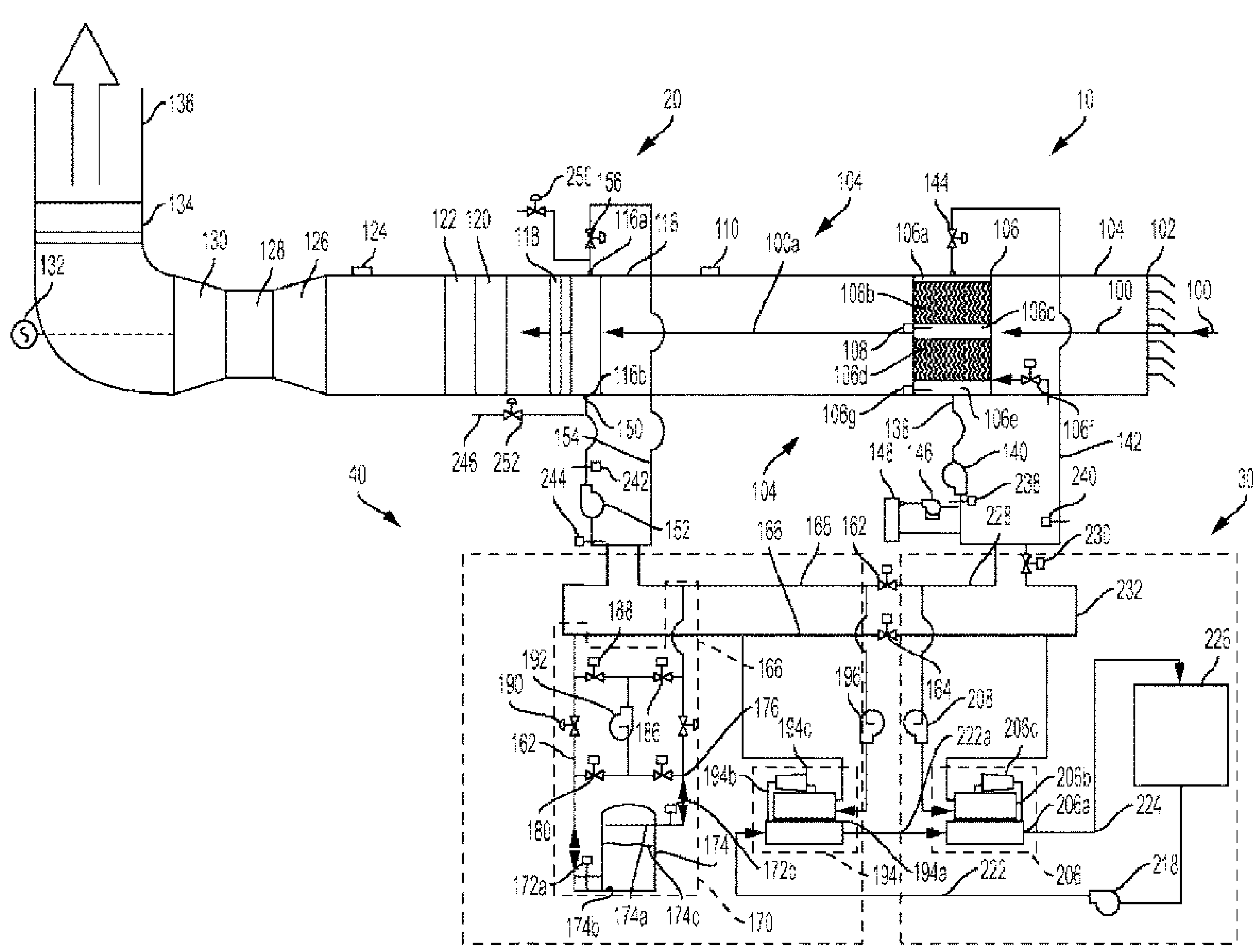
(57) **ABSTRACT**

Embodiments provide a method and apparatus to lower the temperature and heat content of the ambient air at the inlet to a gas combustion turbine to enhance power generation. Embodiments can use multiple, staged direct contact air chillers, variable flow secondary water chilling systems, constant flow primary water chilling systems with water chilling units arranged for parallel chilled water flow, and a coolant water circulation system used for heat rejection with open cooling towers. Alternatives can use a chilled water thermal storage system, and/or waste heat to drive at least part of the water chilling process. With the included apparatus a method to allow adiabatic air chilling is available for operation during periods of lower ambient air conditions when needs for power augmentation may not be as great.

20 Claims, 5 Drawing Sheets



(58) **Field of Classification Search**
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See application file for complete search history.

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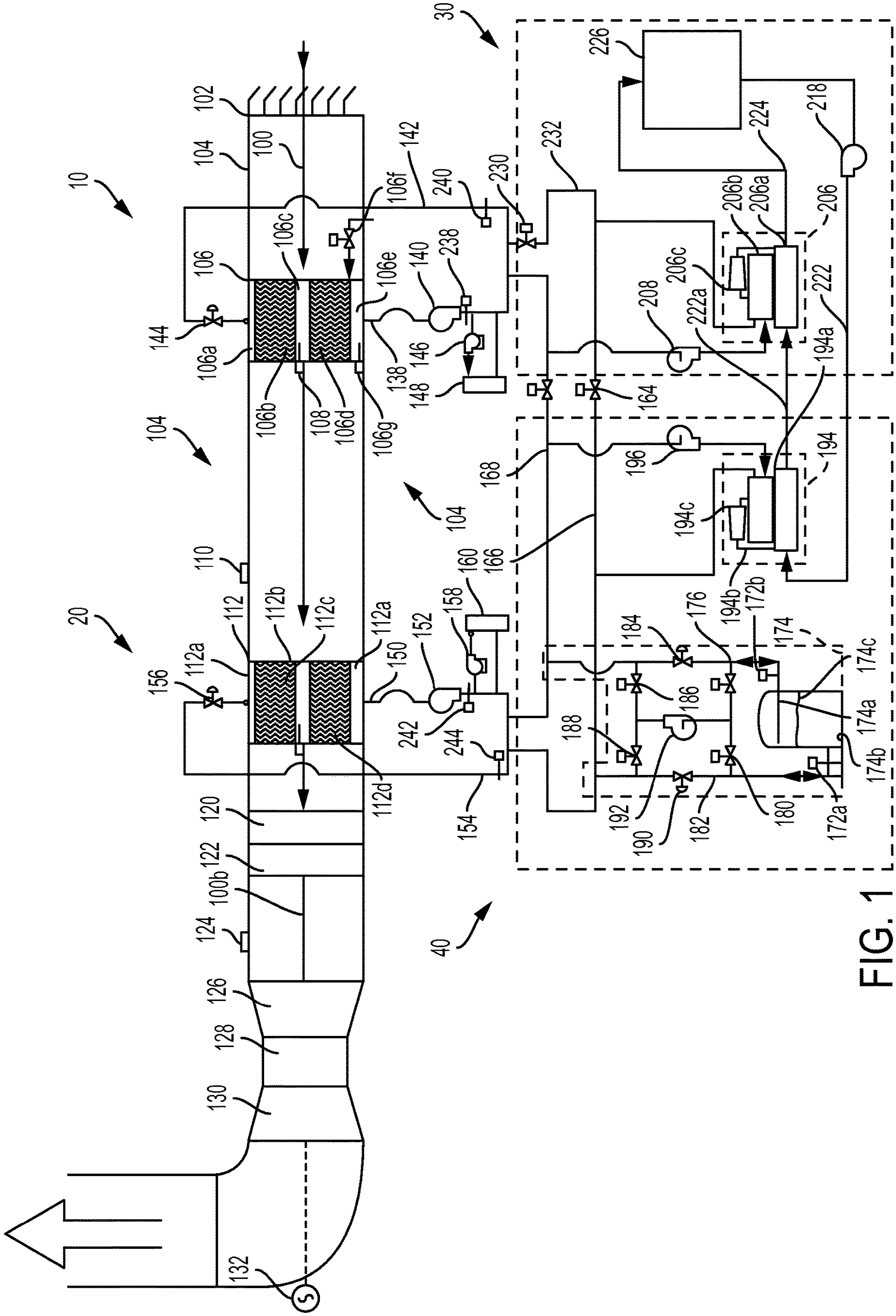
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FIG. 1

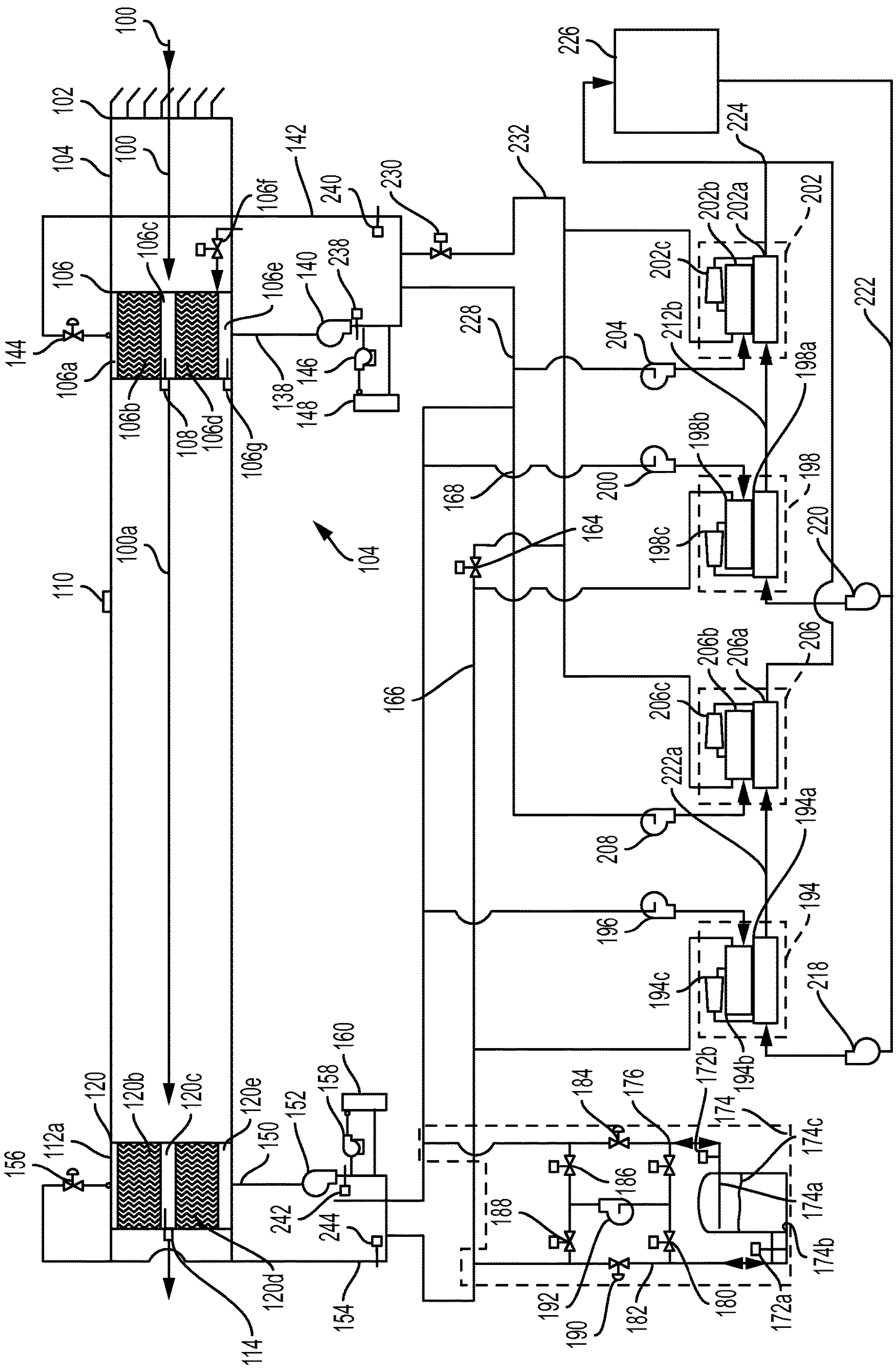
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FIG. 2

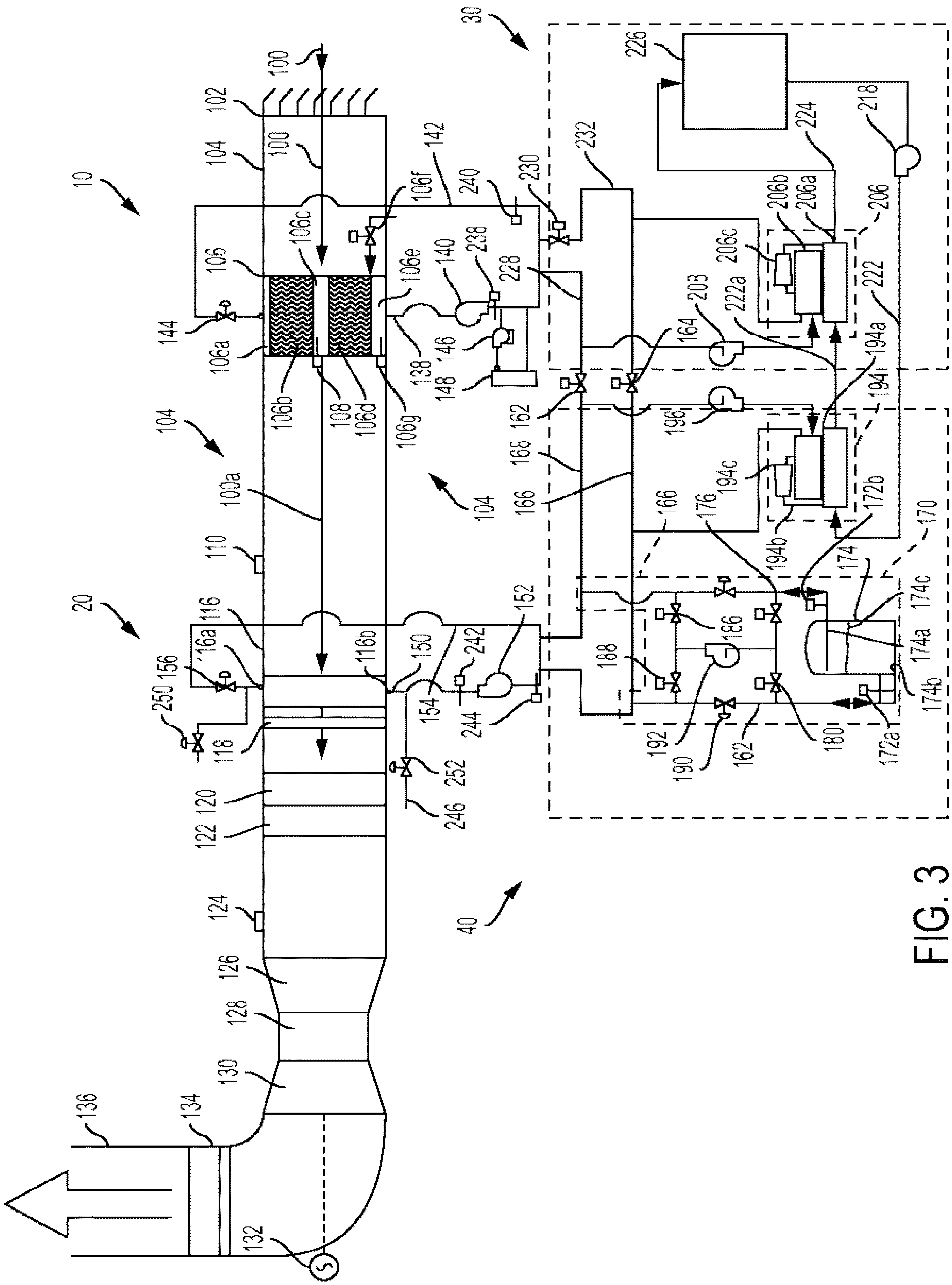

FIG. 3

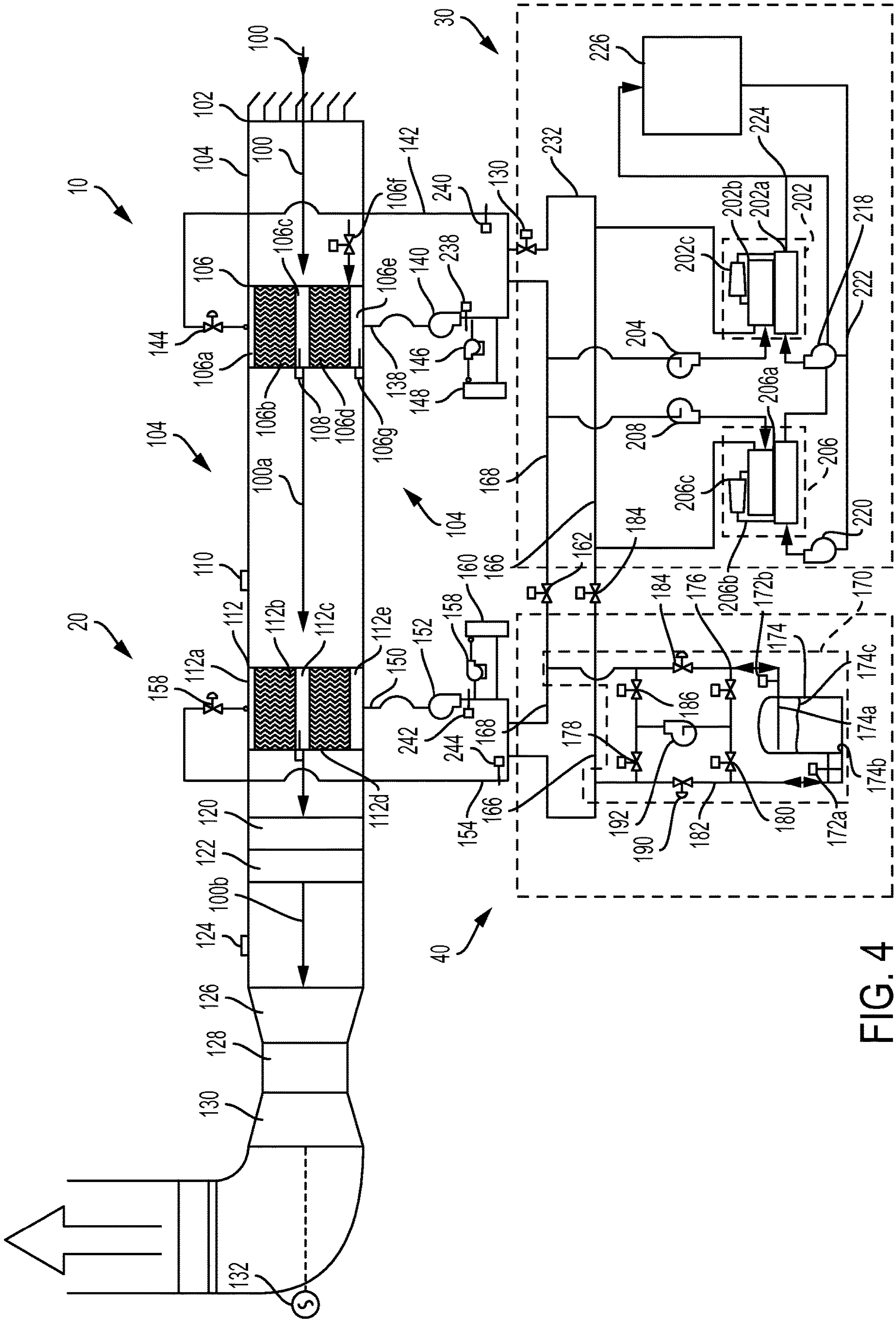

FIG. 4

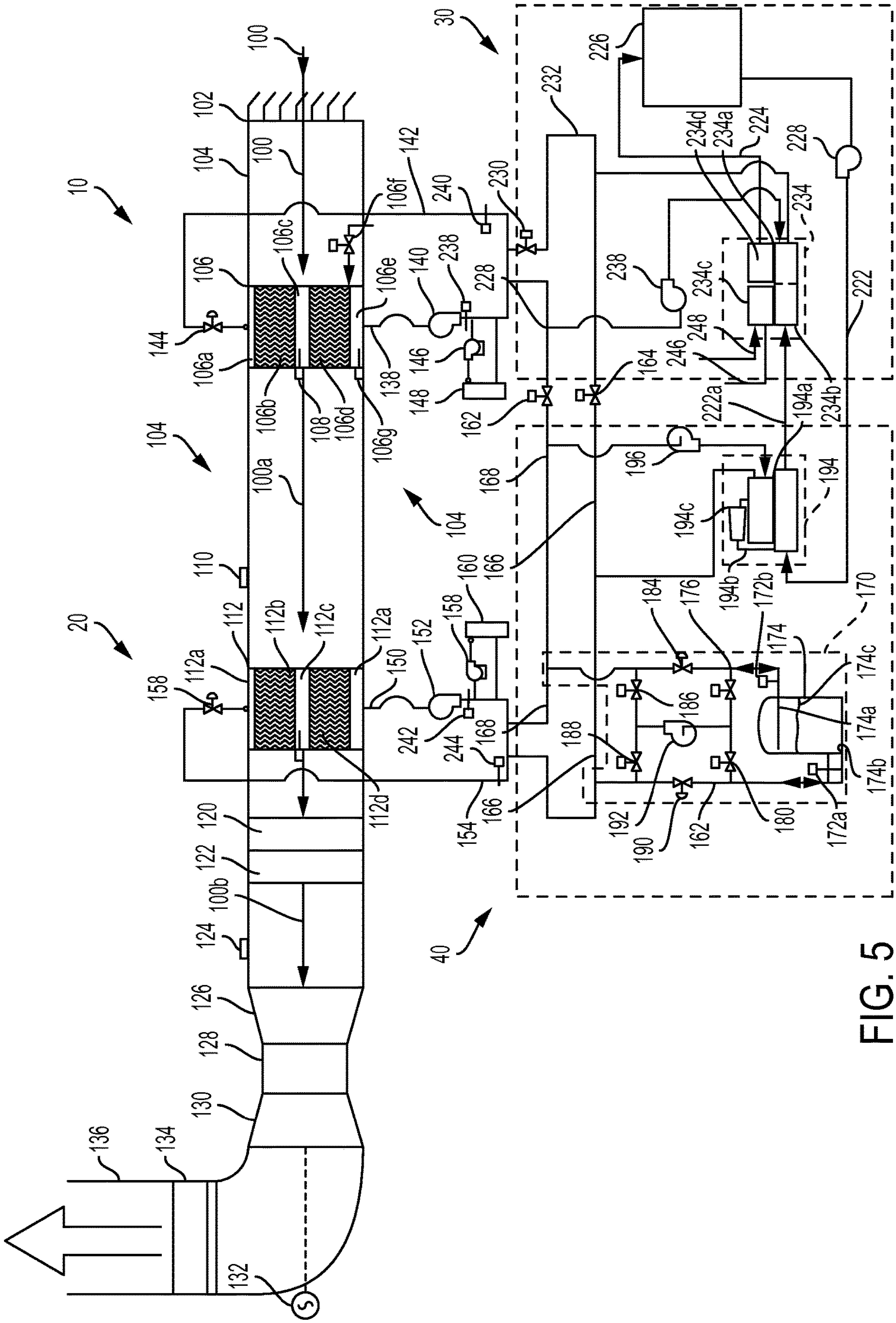
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FIG. 5

METHOD AND APPARATUS FOR COOLING THE AMBIENT AIR AT THE INLET OF GAS COMBUSTION TURBINE GENERATORS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Provisional Patent Application No. 62/069,633, filed on Oct. 28, 2014, and U.S. Provisional Patent Application No. 62/062,493, filed on Oct. 10, 2014, the entire contents of which are incorporated herein by reference.

BACKGROUND

Technical Field

The present invention is in the technical field of electric power generation. More specifically, in the technical field of ambient air cooling at the inlet of gas combustion turbine generators.

Related Art

It is known to use water and air chilling systems to cool the ambient air at the inlet to gas combustion turbine generators. Doing so allows for an increased output of the gas turbines whenever the ambient air temperature is higher than the temperature of the air that can be produced by the chilling systems.

Current practice as presented in active or expired U.S. Pat. Nos. 5,193,352, 5,444,971, 5,790,972, 6,318,065, 6,470,686, and 6,769,258 have deficiencies in regards to energy efficiency when operating at either full design or reduced air cooling loads, and/or flexibility of operation to make use of non-mechanical and/or adiabatic air cooling, and/or in air filtration capability.

BRIEF SUMMARY

Embodiments of the present invention can cool ambient air at the air inlet to turbines in multiple stages by using a combination of indirect contact air chiller devices and direct contact air chiller devices. A direct contact air chiller device can be placed in the upstream or first position to come in contact with the ambient air. The temperature of the air leaving this first air chilling device can be controlled continuously by an industrial automation system, for example, through a combination of water flow rate and temperature set point adjustments. As the air passes through the upstream air chiller device airborne particles can be removed by the water that comes in contact with the air. Air that leaves the upstream air chiller device can enter the first downstream or second position air chiller device to be cooled further. The second position air chiller device can be either an indirect contact or direct contact air chiller. The temperature of the air leaving the second position air chilling device can be controlled continuously by an industrial automation system. Air that leaves the second position air chiller device can enter the gas combustion turbine inlet, or in an alternative case, can enter a third position air chiller device to be further cooled before supply to the gas combustion turbine inlet.

According to embodiments, chilled water that is supplied to each air chiller device can be provided by a water chiller system that is dedicated to the respective air chiller device. Each water chiller system can contain at least one water chiller unit that is arranged so that the chilled water flow is circulated to the evaporator on each water chiller in parallel with the chilled water flow to the other evaporators in the respective water chiller system.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features and advantages of the invention are illustrated from the following drawings, wherein like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements.

FIG. **1** is a schematic that shows an illustrative embodiment of ambient air chilling and water chilling systems at the air inlet to a gas turbine.

FIG. **2** is a schematic that shows a multiple parallel water chiller extension according to an illustrative embodiment.

FIG. **3** is a schematic that shows a first alternate embodiment of apparatus in the ambient air chilling system at the air inlet to a gas turbine.

FIG. **4** is a schematic that shows a second alternate embodiment of apparatus in the ambient air chilling system at the air inlet to a gas turbine.

FIG. **5** is a schematic that shows a third alternate embodiment which alters the type of water chiller units that serve the air chilling system at the air inlet to a gas turbine.

DETAILED DESCRIPTION

Embodiments of the invention are discussed in detail below. In describing embodiments, specific terminology is employed for the sake of clarity. However, the invention is not intended to be limited to the specific terminology so selected. A person skilled in the relevant art will recognize that other equivalent parts can be employed and other methods developed without departing from the spirit and scope of the invention. All references cited herein are incorporated by reference as if each had been individually incorporated.

FIG. **1** depicts an embodiment of a method and apparatus for chilling the ambient air **100** that is drawn through the air inlet of a gas combustion turbine generator. According to an embodiment, the ambient air **100** can be drawn through an inlet air louver **102** and air housing **104** into an air compressor **126**, combustion chamber **128** and gas turbine **130** that is used to drive an electric power generator **132**. As the ambient **100** is drawn through the air housing **104** it can be filtered through pre and high efficiency filters **120** and **122** in order to protect the mechanical operation of the gas turbine **130**. A well-known characteristic of a gas turbine **130** is that as the temperature of the ambient air **100** increases thereby reducing its density, the output energy delivered to the generator **132** is reduced. In order to compensate for the effects of increases to the ambient air **100**, an air cooling system, such as shown at **10** and **20** in FIG. **1**, can be included in the air housing **104**. When an air cooling system is included, it has been common practice to us a single, and not as frequently multiple, indirect contact air chillers, which are comprised of series of tubes through which chilled water circulates so that the air which contacts the outside of the tubes can be cooled. In order to enhance this heat exchange between the air on the outside and the water inside the tubes, fins are typically attached to the outside of the tube so there is more surface contact with the air. An example of this indirect air chiller is shown in an alternate embodiment depicted in FIG. **3** as item **116**.

Embodiments of the invention can use multiple direct contact air coolers shown as item **106** and **112** on FIG. **1**. The water that is supplied to these direct contact air chillers can be chilled by water chiller units, such as **194** and **206** with evaporators **194***b* and **206***b* respectively, that are arranged in parallel with other water chiller units in separate water chiller systems **30** and **40**, example of which are depicted in FIG. **2**. Ambient air enters the first direct contact air chiller **106** at conditions which are as high as 122° F. (50° C.) at 25% relative humidity and passes through polyvinylchloride sheets **106***b* over which chilled water is circulated by action of secondary chilled water pump **140**. Alternative embodiments can use materials such as stainless steel (SS), Polypropylene (PP), Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), or other materials known to one of ordinary skill in the art, instead of the polyvinylchloride sheets described herein. Chilled water enters the direct contact air chiller **106** through flow control valve **144** from supply pipe **142**. Once inside the direct contact air chiller **106** the water can be distributed through channel **106***a* to all polyvinylchloride sheets **106***b* equally, however, unequal distributions are also possible. These polyvinylchloride sheets **106***b* can be arranged substantially vertically so that the water will fall to a water basin/distribution channel **106***c*. As the water falls across polyvinylchloride sheets **106***b* it comes in direct contact with the ambient air **100** thus cooling the ambient air **100** to a lower temperature and total heat content at **100***a*. Water level sensor **108** placed in water basin/distribution channel **106***c* directly modulates flow control valve **144** through a range of positions from full closed to full open in order to maintain the set level in water basin/distribution channel **106***c*. The water can then be distributed through basin/distribution channel **106***c* to all polyvinylchloride sheets **106***d* equally; however, unequal distributions are also possible. These polyvinylchloride sheets **106***d* can be arranged substantially vertically so that the water will fall to a water basin **106***e*. As the water falls across polyvinylchloride sheets **106***b* it comes in direct contact with the ambient air **100** thus cooling the ambient air **100** to a lower temperature and total heat content at **100***a*. The water in basin **106***e* is drained into pipe **138** and then flows to the inlet of pump **140** which has its speed varied by an electronic controller which maintains the water pressure set point for a pressure sensor **238** that is placed at the discharge of pump **140** in pipe **142**. In an alternate embodiment of the direct contact air chiller, chilled water can be distributed to and through channel **106***a* and channel **106***c* in parallel.

The water circulated by secondary chilled water pump **140** can be drawn into a filtering circuit by water filtration pump **146** and then discharged into water filtration equipment **148** where solids are filtered and separated from the water before being injected back into the secondary chilled water circuit. The temperature of the water supplied to direct contact air chiller **106** is continuously monitored at sensor **240** and adjusted through an automation system controller which can use one or more of ambient air **100** conditions, desired gas turbine **130** inlet air conditions **100***b*, and water chilling systems **30** and **40** energy efficiency optimization programs to determine a set point temperature for water chilling system **30**. The water chiller unit or units in water chilling system **30**, such as item **206** shown on FIG. **1**, can be continually controlled to maintain that set point temperature for water chilling. The ambient air temperature and relative humidity conditions after passing through air chiller **106** can be monitored at sensors **110** and the ambient air temperature and relative humidity conditions after passing through air chiller **112** can be monitored at sensors **124**.

According to embodiments, when water chilling is activated to maintain the chilled water set point temperature at sensor **240**, the water chilling system primary chilled water pumps such as pump **208** will activate. Water is drawn by the constant speed primary chilled water pump **208** from the secondary chilled water circuit that serves air chiller system **10** through primary chilled water return pipe **228** to evaporator **206***b* in water chiller unit **206**. The chilled water set point temperature determined for system water chilling system **30** can cause the controls that are part of water chiller unit **206** to adjust operation of the compressor **206***c* to satisfy the set point for sensor **240**. Water supplied from evaporator **206***b* can be supplied through primary chilled water supply pipe **232** to the secondary chilled water system in air chilling system **10** through connection to secondary chilled water supply pipe **142**.

Heat removed from the ambient air **100** in the evaporator **206***b* of the water chiller unit **206** can be transferred to the coolant water in the condenser **206***a* in the water chiller units by action of its compressor **206***c*. Coolant water can be circulated to the condenser **206***a* by action of the condenser water circulating pump **218** first through condenser **194***a* in water chiller unit **194** in water chilling system **40** and then coolant water supply pipe **222***a*. From condenser **206***a* the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226** through coolant water return pipe **224**.

Particles that may be suspended in the ambient air **100** drawn through direct contact air chiller **106** by action of the gas combustion turbine **130** can be cleaned from the ambient air **106** through contact with chilled water on polyvinylchloride sheets **106***b* and **106***d*. This action reduces the filtration load on pre and high efficiency filters **120** and **122**.

Ambient air **100***b* that has been cooled, dehumidified and filtered by passing through direct contact air chiller **106** is drawn into and through direct contact air chiller **112** and passes through polyvinylchloride sheets **112***b* over which chilled water is circulated by action of secondary chilled water pump **152**. Chilled water enters the direct contact air chiller **112** through flow control valve **156** from supply pipe **154**. Once inside the direct contact air chiller **112** the water is distributed through channel **112***a* to all polyvinylchloride sheets **112***b* equally, however, unequal distributions are also possible. These polyvinylchloride sheets **112***b* can be arranged substantially vertically so that the water will fall to a water basin/distribution channel **112***c*. As the water falls across polyvinylchloride sheets **112***b* it comes in direct contact with the ambient air **100***a*, thus cooling the ambient air **100***a* to a lower temperature and total heat content at **100***b*. Water level sensor **114** placed in water basin/distribution channel **112***c* directly modulates flow control valve **156** through a range of positions from full closed to full open in order to maintain the set level in water basin/distribution channel **112***c*. The water can then be distributed through basin/distribution channel **112***c* to all polyvinylchloride sheets **112***d* equally, however, unequal distributions are possible. These polyvinylchloride sheets **112***d* can be arranged substantially vertically so that the water will fall to a water basin **112***e*. As the water falls across polyvinylchloride sheets **112***b* it comes in direct contact with the ambient air **100***a* thus cooling the ambient air **100***a* to a lower temperature and total heat content at **100***b*. The water in basin **112***e* is drained into pipe **150** and then flows to the inlet of pump **152** which has its speed varied by an electronic controller which maintains the water pressure set point for a pressure sensor **242** that is placed at the discharge of pump **152** in pipe **150**.

The water circulated by secondary chilled water pump **152** can be drawn into a filtering circuit by water filtration pump **158** and then discharged into water filtration equipment **160** where solids are filtered and separated from the water before being injected back into the secondary chilled water circuit. The temperature of the water supplied to direct contact air chiller **112** can be continuously monitored at sensor **244** and adjusted through an automation system controller which uses, for example, ambient air **100** conditions, and/or desired gas turbine **130** inlet air conditions **100**_b_, and/or water chilling **30** and **40** energy efficiency optimization programs to determine a set point temperature for water chilling system **40**. The water chiller unit or units or alternate chilled water thermal storage system **170**, in water chilling system **40**, such as item **194** shown on FIG. **1**, can be continually controlled to maintain that set point temperature for water chilling.

When water chilling is activated to maintain the chilled water set point temperature at sensor **244**, the primary chilled water pumps of the water chilling system, for example, pump **196** will activate. Water is drawn by the constant speed primary chilled water pump **196** from the secondary chilled water circuit that serves air chiller system **20**. For example, the water can be drawn through primary chilled water return pipe **168** to evaporator **194**_b_ in water chiller unit **194**. The chilled water set point temperature determined for system water chilling system **40** can cause the controls that are part of water chiller unit **194** to adjust operation of the compressor **194**_c_ to satisfy the set point for sensor **244**. Water supplied from evaporator **194**_b_ can be supplied through primary chilled water supply pipe **166** to the secondary chilled water system in air chilling system **20** through connection to secondary chilled water supply pipe **154**.

Heat removed from the ambient air **100**_a_ in the evaporator **194**_b_ of the water chiller unit **194** can be transferred to the coolant water in the condenser **194**_a_ in the water chiller units by action of its compressor **194**_c_. Coolant water can be circulated to the condenser **194**_c_ by action of the condenser water circulating pump **218** through coolant water supply pipe **222**. From condenser **194**_a_ the coolant water can be circulated to heat rejection apparatus, such as cooling tower **226**, first through condenser **206**_a_ then through coolant water return pipe **224** then to the inlet of cooling tower **226**.

Particles that may be suspended in the ambient air **100**_a_ drawn through direct contact air chiller **112** by action of the gas combustion turbine **130** can be cleaned from the ambient air **100** an additional time through contact with chilled water on polyvinylchloride sheets **112**_b_ and **112**_d_. This action further reduces the air filtration load on pre and high efficiency filters **120** and **122** respectively.

During periods of reduced ambient air **100** cooling load, especially when the moisture content of the ambient air **100** is low, air chilling can be done through use of the direct contact air chiller **106** in an adiabatic mode of operation. According to embodiments, this mode requires no water chilling operation. This mode can be activated through efficiency algorithms which consider, for example, ambient air **100** temperature and moisture content, and/or electric output requirement for the power generator **132**, and/or the set point temperature determined for gas combustion turbine **130** inlet air **100**_b_.

When activated in the adiabatic cooling mode, the flow control valve **144** associated with ambient air chiller **106** will open and water level control **106**_g_ will be enabled to control to the level set point of direct contact air chiller water basin **106**_e_ through signal to water make up control valve **106**_f_. Based on the then current ambient air **100** temperature and moisture content, secondary chilled water pump **140** can be activated. The speed that the secondary chilled water pump **140** will be determined and updated continuously in order to deliver a water flow rate that will minimize the temperature of the ambient air **100**_a_ at the outlet from direct contact air chiller **106**. The ambient air **100** temperature and moisture content can be continuously monitored and the speed of primary chilled water pump **140** can be updated as required to minimize the air temperature at sensor **110**.

According to embodiments, air chilling system **20**, water chilling systems **30** and **40**, and chilled water thermal storage system **170** can be inactive during operation in the adiabatic cooling mode.

In an embodiment of the invention, chilled water provided to air chiller system **20** can be provided by chilled water thermal storage system **170** in parallel with water chiller units, such as water chiller unit **194** within water chilling system **40**. In such case water chiller units in water chilling systems **30** and **40** can operate during designated time periods to charge chilled water into the thermal storage tank **170** at a temperature in the range of, for example, about 38° F. to about 42° F., which will be the set point for any water chiller unit that is activated to charge the chilled water thermal storage tank **174**. In the charge mode of operation, flow control valves **162**, **164**, **178** and **186** will be open, flow control valves **230**, **180** and **188** will be closed, water level control valve **184** will be closed and water level control valve **190** will be activated to maintain the water level in the thermal storage tank **174**. Chilled water thermal storage system circulating pump **192** and primary chilled water pumps in water chiller systems **30** and **40**, such as pumps **196** and **208** will be activated. This action can cause flow to be induced from primary chilled water return pipes **168** and **228** to the primary chilled water pumps **196** and **208**, to and through the water chiller evaporators **194**_b_ and **206**_b_, through primary chilled water supply pipes **232** and **166**, through water level control valve **190** and chilled water pipe **182**, to water distribution pipe **174**_b_ at the bottom of chilled water thermal storage tank **174**. Water at or near 40° F. is denser than the warmer temperature water in the tank from the previous discharge mode.

Accordingly, the water entering the bottom of the tank **174** can remain near the bottom, displacing warmer water which will distribute through the thermal storage tank **174** to the tank top water distribution pipe **174**_a_. Chilled water thermal storage system pump **192** can draw the warm water through the tank top water distribution pipe **174**_a_ through chilled water pipe **176** to primary chilled water return pipes **168** and **228** which will direct water back to the primary chilled water pumps **196** and **208**. During the charging of the chilled water thermal storage tank, a boundary layer **174**_c_ of water will form between the cold and warm water. This boundary layer **174**_c_ has a temperature transition from cold to warm that extends through the boundary layer from its bottom to top which can be approximately 2 feet (600 mm) and is often referred to as a "thermocline." During the charge mode of operation, the thermocline **174**_c_ moves upwards as the thermal storage tank **174** fills with chilled water. Thus, the warm water leaving the thermal storage tank **174** cools as the thermocline nears the top water distribution pipe **174**_a_. According to embodiments, the thermal storage tank charge mode will be terminated when the water temperature monitored at sensor **172**_b_ at the top connection to the storage tank **174** is less than about 4.0° F. higher than the water temperature monitored at sensor **172**_a_ at the bottom connection to the storage tank **174**.

During the discharge mode of operation for chilled water thermal storage system **170**, flow control valves **162**, **164**, **178** and **186** are closed, flow control valves **230**, **180** and

188 are open, and water level control valve **190** is closed. Water level control valve **184** is activated to maintain the set water level in the thermal storage tank **174**. Chilled water thermal storage system circulating pump **192** can then be activated. This action will cause flow to be induced from the storage tank **174** through the tank bottom distribution pipe **174***b* and flow control valve **180** to the inlet of thermal storage system circulating pump **192**. From the outlet of thermal storage system circulating pump **192**, chilled water circulates through flow control valve **188** and chilled water pipe **182** to primary chilled water supply pipe **166**, where it can be combined with flow from water chillers in water chilling system **40** to supply chilled water into the secondary chilled water system that serves air chilling system **20** at pipe **154**. Warm water returning from the secondary chilled water system that serves air chilling system **20** circulates through pipe **150** and secondary chilled water pumps **152** to primary water chiller system **40** at the connection with primary chilled water return pipe **168**. Water flow from primary chilled water return pipe **168** will then circulate through chilled water pipe **176** and thermal storage tank level control valve **184** into the thermal storage tank **174** through the connection to the tank top water distribution pipe **174***a*. Since water at or near 40° F. is denser than the warmer temperature water that is entering the thermal storage tank through distribution pipe **174***a*, the warm water will continue to accumulate near the top of the thermal storage tank **174** while the colder water is reduced in the area below the thermocline **174***c*.

FIG. **2** illustrates another embodiment of the present invention that arranges multiple water chiller units into water chilling systems **30** and **40**. When multiple chiller units are used in water chilling system **30**, such as adding water chiller unit **202** to operate with water chiller unit **206**, the primary chilled water piping **228** and **230**, and primary chilled water pump **204** can be arranged so that the evaporator **202***b* in water chiller unit **202** operates in parallel with the evaporator **206***b* in water chiller unit **206** as needed for all modes of operation. When multiple chiller units are used in water chilling system **40**, such as adding water chiller unit **198** to operate with water chiller unit **194**, the primary chilled water piping **166** and **168**, and primary chilled water pump **200** can be arranged so that the evaporator **198***b* in water chiller unit **198** operates in parallel with the evaporator **194***b* in water chiller unit **194** as needed for all modes of operation.

In embodiments of water chilling system **30** with multiple water chiller units, when water chilling is activated to maintain the chilled water set point temperature at sensor **240**, the water chilling system primary chilled water pumps **204** and **208** will activate. Water is drawn by the constant speed primary chilled water pumps **204** and **208** from the secondary chilled water circuit that serves air chiller system **10** through primary chilled water return pipe **228** to evaporators **202***b* and **206***b* in water chiller unit **202** and **206**, respectively. The chilled water set point temperature determined for water chilling system **30** can cause the controls that are part of water chiller units **202** and **206** to adjust operation of the compressors **202***c* and **206***c* to satisfy the set point for sensor **240**. Water supplied from evaporators **202***b* and **206***b* can be supplied through primary chilled water supply pipe **232** to the secondary chilled water system in air chilling system **20** through connection to secondary chilled water supply pipe **142**.

Heat removed from the ambient air **100** in the evaporators **202***b* and **206***b* of the water chiller unit **202** and **206** can be transferred to the coolant water in the condenser **202***a* and **206***a* in the water chiller units by action of its compressors **202***c* and **206***c*. Coolant water can be circulated to the condenser **202***a* by action of the condenser water circulating pump **220**, for example, first through condensers **198***a* in water chiller unit **198** in water chilling system **40** and then through coolant water supply pipe **222***b*. From condenser **202***a* the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226**, through coolant water return pipe **224**. Coolant water can be circulated to the condenser **206***a* by action of the condenser water circulating pump **218** first through condensers **194***a* in water chiller unit **194** in water chilling system **40** and then through coolant water supply pipe **222***a*. From condenser **206***a* the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226**, through coolant water return pipe **224**.

According to embodiments, when water chilling is activated to maintain the chilled water set point temperature at sensor **244**, the water chilling system primary chilled water pumps **196** and **200** will activate. Water is drawn by the constant speed primary chilled water pump **196** and **200** from the secondary chilled water circuit that serves air chiller system **20** through primary chilled water return pipe **168** to evaporator **194***b* in water chiller unit **194** and to evaporator **198***b* in water chiller unit **198**. The chilled water set point temperature determined for system water chilling system **40** can cause the controls that are part of water chiller units **194** and **198** to adjust operation of the compressor **194***c* and **198***c* to satisfy the set point for sensor **244**. Water supplied from evaporators **194***b* and **198***b* can be supplied through primary chilled water supply pipe **166** to the secondary chilled water system in air chilling system **20** through connection to secondary chilled water supply pipe **154**.

Heat removed from the ambient air **100***a* in the evaporator **194***b* and **198***b* of the water chiller unit **194** and **198** can be transferred to the coolant water in the condensers **194***a* and **198***a* in the water chiller units by action of its compressor **194***c* and **198***c*. Coolant water can be circulated to the condenser **194***c* by action of the condenser water circulating pump **218** through coolant water supply pipe **222**. From condenser **194***a*, the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226**, first through condenser **206***a* then through coolant water return pipe **224** then to the inlet of cooling tower **226**. Coolant water can be circulated to the condenser **198***c* by action of the condenser water circulating pump **220** through coolant water supply pipe **222**. From condenser **198***a*, the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226**, first through condenser **202***a* then through coolant water return pipe **224** then to the inlet of cooling tower **226**.

According to embodiments, operation of air chilling systems **10** and **20** and chilled water thermal storage system **170** are the same, or substantially the same, as described above in connection with the description for FIG. **1** whenever multiple water chiller units are used.

Embodiments of the invention shown in FIG. **1** and FIG. **2** can provide advantages over the prior art. These advantages can result from, among other things, one or more of the following features. Embodiments can provide an improvement in energy use that is enabled by the direct contact of the chilled water with the ambient air **100** in air chiller **106** and **112**. This direct contact can eliminates the resistance to heat transfer that occurs in an indirect contact air chiller, which in turn, can allow the water chiller systems **30** and **40** to provide water at a higher, more efficient chilled water supply temperature than could be the case when either single or multiple indirect air chillers are used.

Additionally or alternatively, embodiments of the invention can provide a substantial reduction in the amount of air borne particulate that enters the pre and high efficiency air filters **120** and **122** respectively. This feature can extend the life and effectiveness of the air filters **120** and **122**, for example, by three to four times, when compared against the prior art which places the air filters upstream in the direction of ambient air **100** flow prior to the indirect contact air chiller coils.

Additionally or alternatively, embodiments of the invention can combine the efficiency gained by using direct contact air coolers with using an upstream water chilling system **30** that allows about 35% to about 50% of the total ambient air cooling load to be provided at a chilled water temperature that is more than about 20° F. higher than the chilled water temperature that is required to chill the ambient air to the desired gas combustion turbine inlet air temperature. Embodiments of the invention described herein can provide air chilling system total energy savings of approximately 12% when compared against prior art, and the use of direct contact air coolers in combination with an upstream water chilling system **30** can account for approximately 60% of that total energy savings.

FIG. **3** illustrates an alternate embodiment of the invention presented in FIG. **1**. This alternative uses an indirect contact air chiller **116** in place of the direct contact air chiller **112**. In this alternative the operation of air chiller system **20** and water chilling system **40** are described in the following manner.

Ambient air **100***b* that has been cooled, dehumidified and filtered by passing through direct contact air chiller **106** is drawn into and through indirect contact air chiller **116**. Chilled water enters the supply connection **116***a* to the tubes in the indirect contact air chiller **116** through flow control valve **156** from supply pipe **154**. Once inside the indirect contact air chiller **116**, the water is distributed through all tube rows equally thus cooling the ambient air **100***a* to a lower temperature and total heat content at **100***b*. However, according to alternative embodiments, the water can be distributed unequally through the tube rows. The air temperature and relative humidity sensors **124** placed in the ambient air **100***b* at the air exit from indirect contact air chiller directly modulate flow control valve **156** through a range of positions from full closed to full open in order to maintain the set point temperature for the ambient air **100***b* as monitored by sensor at the entrance to the gas combustion turbine **130**. The water in indirect contact air chiller **116** then exits through chilled water return connection **116***b* and then flows to the inlet of pump **152** which has its speed varied by an electronic controller which maintains the water pressure set point for a pressure sensor **242** that is placed at the discharge of pump **152** in pipe **150**.

The temperature of the water supplied to indirect contact air chiller **116** can be continuously monitored at sensor **244** and adjusted through an automation system controller which uses, for example, ambient air **100** conditions, and/or desired gas turbine **130** inlet air conditions **100***b*, and/or water chilling systems **30** and **40** energy efficiency optimization programs to determine a set point temperature for water chilling system **40**. The water chiller unit or units or alternate chilled water thermal storage system **170**, in water chilling system **40**, such as item **194** shown on FIG. **1**, can be continually controlled to maintain that set point temperature for water chilling.

When water chilling is activated to maintain the chilled water set point temperature at sensor **244**, the water chilling system primary chilled water pumps, such as pump **196**, will activate. Water can be drawn by the constant speed primary chilled water pump **196** from the secondary chilled water circuit that serves air chiller system **20** through primary chilled water return pipe **168** to evaporator **194***b* in water chiller unit **194**. The chilled water set point temperature determined for system water chilling system **40** can cause the controls that are part of water chiller unit **194** to adjust operation of the compressor **194***c* to satisfy the set point for sensor **244**. Water supplied from evaporator **194***b* can be supplied through primary chilled water supply pipe **166** to the secondary chilled water system in air chilling system **20** through connection to secondary chilled water supply pipe **154**.

Heat removed from the ambient air **100***a* in the evaporator **194***b* of the water chiller unit **194** can be transferred to the coolant water in the condenser **194***a* in the water chiller units by action of its compressor **194***c*. Coolant water can be circulated to the condenser **194***c* by action of the condenser water circulating pump **218** through coolant water supply pipe **222**. From condenser **194***a*, the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226** first through condenser **206***a* then through coolant water return pipe **224** then to the inlet of cooling tower **226**.

In this embodiment waste heat in the form of steam or heated water can be supplied by heat recovery steam generator **134** that captures heat from the exhaust gas **136** discharged from gas combustion turbine **130**. Heat to drive the heating of the ambient air **100** can be provided from the heat recovery steam generator **134** through supply pipe **248**. The flow of steam or heated water can be regulated by flow control valve **250** in order to maintain the temperature set point for sensor **124** at the inlet of the gas combustion turbine **130**. Return of the steam condensate or heated water to the heat recovery steam generator **134** can be through flow control valve **252** and pipe **246**.

According to embodiments, the description for ambient air chilling system **10**, water chilling system **30**, and chilled water thermal storage system **170** are the same or substantially the same as stated in the description for FIG. **1**.

FIG. **4** illustrates another alternate embodiment of the invention presented in FIG. **1**. This alternative uses chilled water thermal storage for all chilling that is provided by water chilling system **40** and therefore all air chilling that is provided by air chilling system **20**. In this alternative, the operation of air chiller system **20** and water chilling system **30** are described in the following manner.

In the embodiment of FIG. **4**, water chiller units in water chilling system **30** operate during designated time periods to charge chilled water into the thermal storage tank **170** at a temperature in the range of, for example, about 38° F. to about 42° F., which will be the set point for any water chiller unit that is activated to charge the chilled water thermal storage tank **174**. In the charge mode of operation, flow control valves **162**, **164**, **178** and **186** are open, flow control valves **230**, **180** and **188** are closed, water level control valve **184** is closed and water level control valve **190** is activated to maintain the set water level in the thermal storage tank **174**. Chilled water thermal storage system circulating pump **192** and primary chilled water pumps in water chiller systems **30**, such as pumps **204** and **208**, will be activated. This action can cause flow to be induced from primary chilled water return pipes **168** and **228** to the primary chilled water pumps **204** and **208**, to and through the water chiller evaporators **202***b* and **206***b*, through primary chilled water supply pipes **232** and **166**, through water level control valve **190** and chilled water pipe **182**, to water distribution pipe **174***b* at the bottom of chilled water thermal storage tank **174**. Since water at or near 40° F. is denser than the warmer temperature water in the tank from the previous discharge mode, the water entering the bottom of the tank **174** will remain near the bottom, displacing warmer water which will distribute through the thermal storage tank **174** to the tank top water distribution pipe **174***a*. Chilled water thermal storage system pump **192** can draw the warm water through the tank top water distribution pipe **174***a* through chilled water pipe **176** to primary chilled water return pipes **168** and **228** which will communicate water back to the primary chilled water pumps **196** and **208**. During the charging of the chilled water thermal storage tank, a boundary layer **174***c* of water will form between the cold and warm water. This boundary layer **174***c* has a temperature transition from cold to warm that extends through the boundary layer from its bottom to top which is approximately 2 feet (600 mm) and is often referred to as a "thermocline." During the charge mode of operation, the thermocline **174***c* moves upwards as the thermal storage tank **174** fills with chilled water. Thus, the warm water leaving the thermal storage tank **174** will cool as the thermocline nears the top water distribution pipe **174***a* and the thermal storage tank charge mode will be terminated when the water temperature monitored at sensor **172***b* at the top connection to the storage tank **174** is less than about 4.0° F. higher than the water temperature monitored at sensor **172***a* at the bottom connection to the storage tank **174**.

In the discharge mode of operation for chilled water thermal storage system **170**, flow control valves **162**, **164**, **178** and **186** are closed, flow control valves **230**, **180** and **188** are open, water level control valve **190** are closed and water level control valve **184** are activated to maintain the set water level in the thermal storage tank **174**. Chilled water thermal storage system circulating pump **192** will then be activated. This action will cause water flow to be induced from the storage tank **174** through the tank bottom distribution pipe **174***b* and flow control valve **180** to the inlet of thermal storage system circulating pump **192**. From the outlet of thermal storage system circulating pump **192**, chilled water will circulate through flow control valve **188** and chilled water pipe **182** to primary chilled water supply pipe **166** where it can supply chilled water into the secondary chilled water system that serves air chilling system **20** at pipe **154**. The temperature of the water supplied to direct contact air chiller **112** can be continuously monitored at sensor **244** and adjusted through an automation system controller which uses ambient air **100** conditions, and the desired gas turbine **130** inlet air conditions **100** to determine a set point temperature for water chilling system **40**. The speed of chilled water thermal storage system circulation pump **192** can be controlled to inject chilled water supply water from thermal storage tank **174** in order to maintain the set point that is determined for water chilling system **40**.

Warm water returning from the secondary chilled water system that serves air chilling system **20** can circulate through pipe **150** and secondary chilled water pumps **152** to primary water chiller system **40** at the connection with primary chilled water return pipe **168**. Water flow from primary chilled water return pipe **168** can then circulate through chilled water pipe **176** and thermal storage tank level control valve **184** into the thermal storage tank **174** through the connection to the tank top water distribution pipe **174***a*. Since water at or near 40° F. is denser than the warmer temperature water that is entering the thermal storage tank through distribution pipe **174***a*, the warm water will continue to accumulate near the top of the thermal storage tank **174** while the colder water is reduced in the area below the thermocline **174***c*.

As shown in FIG. **4**, multiple chiller units are used in water chilling system **30**, wherein water chiller unit **202** can operate with water chiller unit **206**. The primary chilled water piping **228** and **230** and primary chilled water pumps **204** and **208** can be arranged so that the evaporator **202***b* in water chiller unit **202** operates in parallel with the evaporator **206***b* in water chiller unit **206** as needed for supplying chilled water to the secondary chilled water system that serves ambient air chilling system **10**.

For embodiments of water chilling system **30** having multiple water chiller units, when water chilling is activated to maintain the chilled water set point temperature at sensor **240**, the water chilling system primary chilled water pumps **204** and **208** will activate. Water is drawn by the constant speed primary chilled water pumps **204** and **208** from the secondary chilled water circuit that serves air chiller system **10** through primary chilled water return pipe **228** to evaporators **202***b* and **206***b* in water chiller unit **202** and **206**, respectively. The chilled water set point temperature determined for system water chilling system **30** can cause the controls that are part of water chiller units **202** and **206** to adjust operation of the compressors **202***c* and **206***c* to satisfy the set point for sensor **240**. Water supplied from evaporators **202***b* and **206***b* can be supplied through primary chilled water supply pipe **232** to the secondary chilled water system in air chilling system **10** through connection to secondary chilled water supply pipe **142**.

Heat removed from the ambient air **100** in the evaporators **202***b* and **206***b* of the water chiller unit **202** and **206** can be transferred to the coolant water in the condenser **202***a* and **206***a* in the water chiller units by action of its compressors **202***c* and **206***c*. Coolant water can be circulated in parallel to the condenser **202***a* and **206***a* by action of the condenser water circulating pumps **218** and **220**, respectively. From condensers **202***a* and **206***a* the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226**, through coolant water return pipe **224**.

According to embodiments, the description for ambient air chilling system **10** can be the same, or substantially the same, as stated in the description for FIG. **1**.

FIG. **5** illustrates another alternate embodiment of the invention presented in FIG. **1**. This alternative uses at least one waste heat driven lithium bromide absorption water chiller unit in lieu of electric driven water chiller units to supply all chilling that is provided by water chilling system **30**, and therefore all air chilling that is provided by air chilling system **10**. In this alternative the operation of water chiller system **30** is described in the following manner.

Waste heat in the form of steam or heating water can be supplied by heat recovery steam generator **134** that captures heat from the exhaust gas **136** discharged from gas combustion turbine **130**. Heat to drive the reaction in the absorption chiller unit and produce water as cold as, for example, about 40° F. can be provided from the heat recovery steam generator through supply pipe **246**. Return of the steam or heating water to the heat recovery steam generator **134** occurs through pipe **246**.

When water chilling is activated to maintain the chilled water set point temperature at sensor **240**, the water chilling system primary chilled water pumps, such as pump **236**, will activate. Water can be drawn by the constant speed primary chilled water pump **236** from the secondary chilled water circuit that serves air chiller system **10** through primary chilled water return pipe **228** to evaporator **234***a* in water chiller unit **234**. The chilled water set point temperature determined for system water chilling system **30** can cause the controls that are part of water chiller unit **234** to adjust operation to satisfy the set point for sensor **240**. Water supplied from evaporator **234***a* can be supplied through primary chilled water supply pipe **232** to the secondary chilled water system in air chilling system **10** through connection to secondary chilled water supply pipe **142**.

Heat removed from the ambient air **100** in the evaporator **234***a* of the water chiller unit **234** can be transferred to the coolant water in the condenser **234***b* in the water chiller unit **234**. Coolant water can be circulated to the condenser **234***b* by action of the condenser water circulating pump **228**, first through condenser **194***a* in water chiller unit **194** in water chilling system **40**, and then through coolant water supply pipe **222***a*. From condenser water outlet at **234***d* the coolant water can be circulated to heat rejection apparatus, for example, cooling tower **226**, through coolant water return pipe **224**.

According to embodiments, the description for ambient air chilling systems **10** and **20**, water chilling system **40**, and chilled water thermal storage system **170** can be the same, or substantially the same, as stated in the description for FIG. **1**.

The embodiments illustrated and discussed in this specification are intended only to teach those skilled in the art the best way known to the inventors to make and use the invention. Nothing in this specification should be considered as limiting the scope of the present invention. All examples presented are representative and non-limiting. The above-described embodiments of the invention may be modified or varied, without departing from the invention, as appreciated by those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the claims and their equivalents, the invention may be practiced otherwise than as specifically described.

I claim:

1. A direct contact air chiller for chilling inlet air to a gas turbine comprising:
- a first plurality of sheets;
- a second plurality of sheets;
- a first distribution channel configured to receive chilled water from a supply pipe and distribute the chilled water to the first plurality of sheets;
- a second distribution channel located between the first plurality of sheets and the second plurality of sheets, the second distribution channel configured to receive the chilled water directly from the first plurality of sheets and distribute the chilled water to the second plurality of sheets;
- a water level sensor placed in the second distribution channel and configured to sense a water level in the second distribution channel; and
- a flow control valve located on the supply pipe,
- wherein the water level sensor directly modulates the flow control valve through a range of positions in order to maintain a predetermined water level in the second distribution channel, and
- wherein the direct contact air chiller is configured to chill, dehumidify, and filter inlet air flowing through the direct contact air chiller.

2. The direct contact air chiller of claim **1**, wherein chilled water distributed to the first plurality of sheets and the second plurality of sheets are configured to chill inlet air by direct contact between the chilled water and inlet air.

3. The direct contact air chiller of claim **2**, wherein chilled water distributed to the first plurality of sheets and the second plurality of sheets are configured to mechanically filter particles from the inlet air by direct contact between the chilled water and inlet air.

4. The direct contact air chiller of claim **3**, further comprising a water basin for collecting chilled water from the first plurality of sheets and the second plurality of sheets, wherein the water basin is configured to drain the chilled water from the direct contact air chiller.

5. The direct contact air chiller of claim **3**, wherein the first plurality of sheets and the second plurality of sheets are selected from the group consisting of polyvinylchloride sheets, polypropylene sheets, polyethylene terephthalate sheets, high-density polyethylene sheets, and stainless steel sheets.

6. The direct contact air chiller of claim **3**, wherein each of the first plurality of sheets and the second plurality of sheets are arranged vertically.

7. The direct contact air chiller of claim **3**, wherein the first distribution channel is configured to distribute chilled water equally to the first plurality of sheets and wherein the second distribution channel is configured to distribute chilled water equally to the second plurality of sheets.

8. The direct contact air chiller of claim **3**, wherein the first distribution channel is configured to distribute chilled water unequally to the first plurality of sheets and wherein the second distribution channel is configured to distribute chilled water unequally to the second plurality of sheets.

9. The direct contact air chiller of claim **1**, wherein the range of positions of the flow control valve is between full closed to full open.

10. The direct contact air chiller of claim **1**, further comprising a sensor configured to continuously monitor a temperature of the chilled water in the supply pipe, wherein the temperature of the chilled water is configured to be adjusted through an automation system controller based on one or more of ambient air conditions, desired gas turbine inlet air conditions, energy efficiency optimization programs of a water chilling system.

11. A system comprising:
- the direct contact air chiller of claim **1**;
- an indirect contact air chiller; and
- one or more water chilling systems,
- wherein inlet air is chilled, dehumidified, and filtered in the direct contact air chiller before being drawn into and through the indirect contact air chiller.

12. A method of chilling inlet air to the gas turbine comprising:
- supplying chilled water to the direct contact air chiller of claim **1**;
- distributing chilled water to the first and second plurality of sheets;
- directly contacting inlet air with the chilled water distributed to the first and second plurality of sheets;
- chilling inlet air with the chilled water distributed to the first and second plurality of sheets; and
- filtering inlet air with the chilled water distributed to the first and second plurality of sheets.

13. The method of chilling inlet air of claim **12**, wherein directly contacting inlet air with the chilled water distributed to the first and second plurality of sheets simultaneously chills and filters the inlet air.

14. The method of chilling inlet air of claim **12**, wherein distributing chilled water to the first and second plurality of sheets comprises equally distributing chilled water to the first and second plurality of sheets.

15. The method of chilling inlet air of claim **12**, wherein distributing chilled water to the first and second plurality of sheets comprises unequally distributing chilled water to the first and second plurality of sheets.

16. The method of chilling inlet air of claim **12**, wherein filtering inlet air comprises mechanically filtering particles from the inlet air with the chilled water distributed to the first and second plurality of sheets.

17. The method of chilling inlet air of claim **16**, further comprising draining the chilled water from the first and second plurality of sheets after mechanically filtering particles from the inlet air, and pumping chilled water having the filtered particles therein through a filtering circuit in order to remove the particles from the chilled water.

18. The method of chilling inlet air of claim **12**, further comprising providing the first and second distribution channels for distributing chilled water to the first and second plurality of sheets, and providing a water basin for draining chilled water from the first and second plurality of sheets.

19. The method of chilling inlet air of claim **18**, further comprising sensing the water level in the second distribution channel and the water level in the water basin.

20. The method of chilling inlet air of claim **18**, further comprising maintaining the predetermined water level in the second distribution channel and a predetermined water level in the water basin.

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